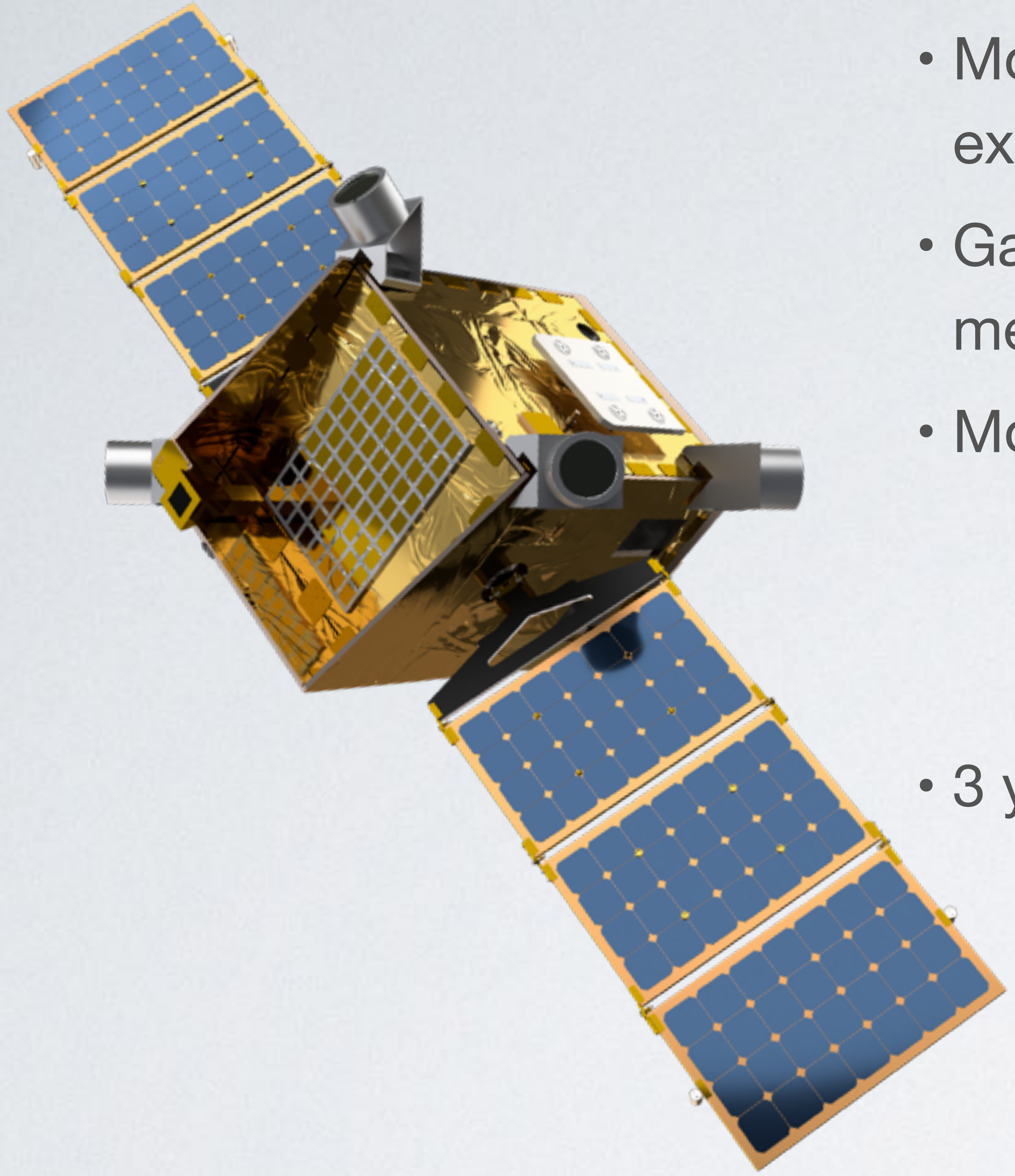
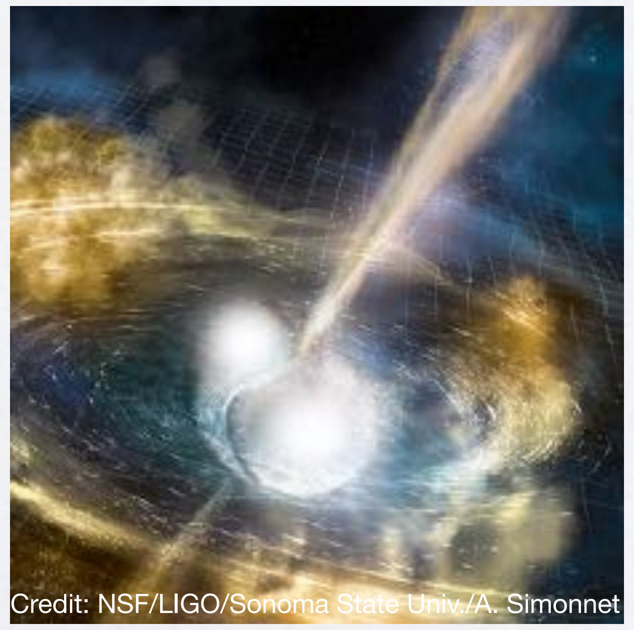
Moon Burst Energetics All-sky Monitor

OVERVIEW

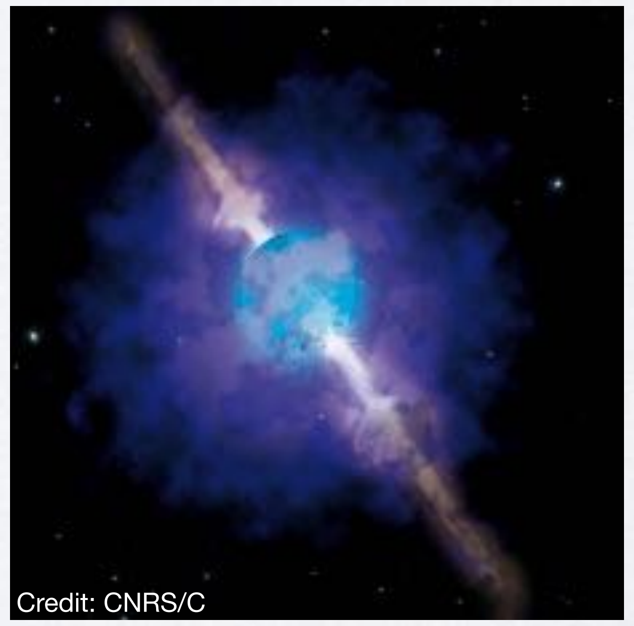


- Moon Burst Energetics All-sky Monitor is 3-year gamma-ray mission in cislunar orbit to explore the behavior of matter and energy under extreme conditions.
- Gamma-ray observations are an essential component to multi-wavelength and multi-messenger observations of relativistic astrophysical explosions.
- MoonBEAM provides key capabilities that are difficult to achieve in Low Earth Orbit:
  - instantaneous all-sky gamma-ray field of view
  - uninterrupted observations with >96% duty cycle
  - background radiation stability
- 3 years of mission operation will provide observations of:
  - 1600 binary compact mergers
  - 5900 optically discovered core collapse supernovae
  - 140 magnetar giant flares
  - and enables 55 very high energy gamma-ray and 360 optical follow-up observations.



Credit: NSF/LIGO/Sonoma State Univ./A. Simonnet

Credit: Carl Knox, OzGrav-Swinburne University



Credit: CNRS/C

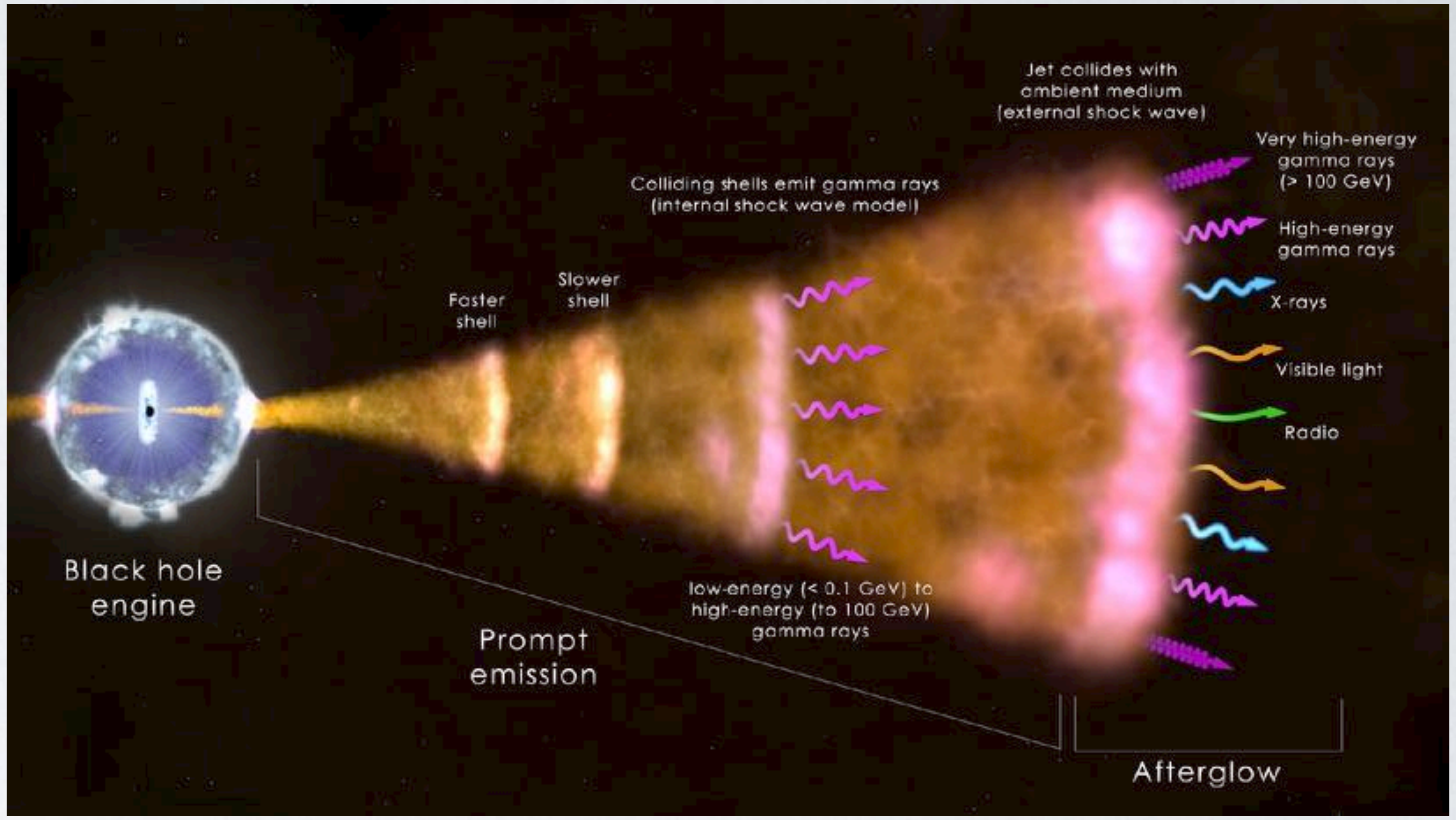
Credit: NASA GSFC/Chris Smith (USRA/GESTAR)

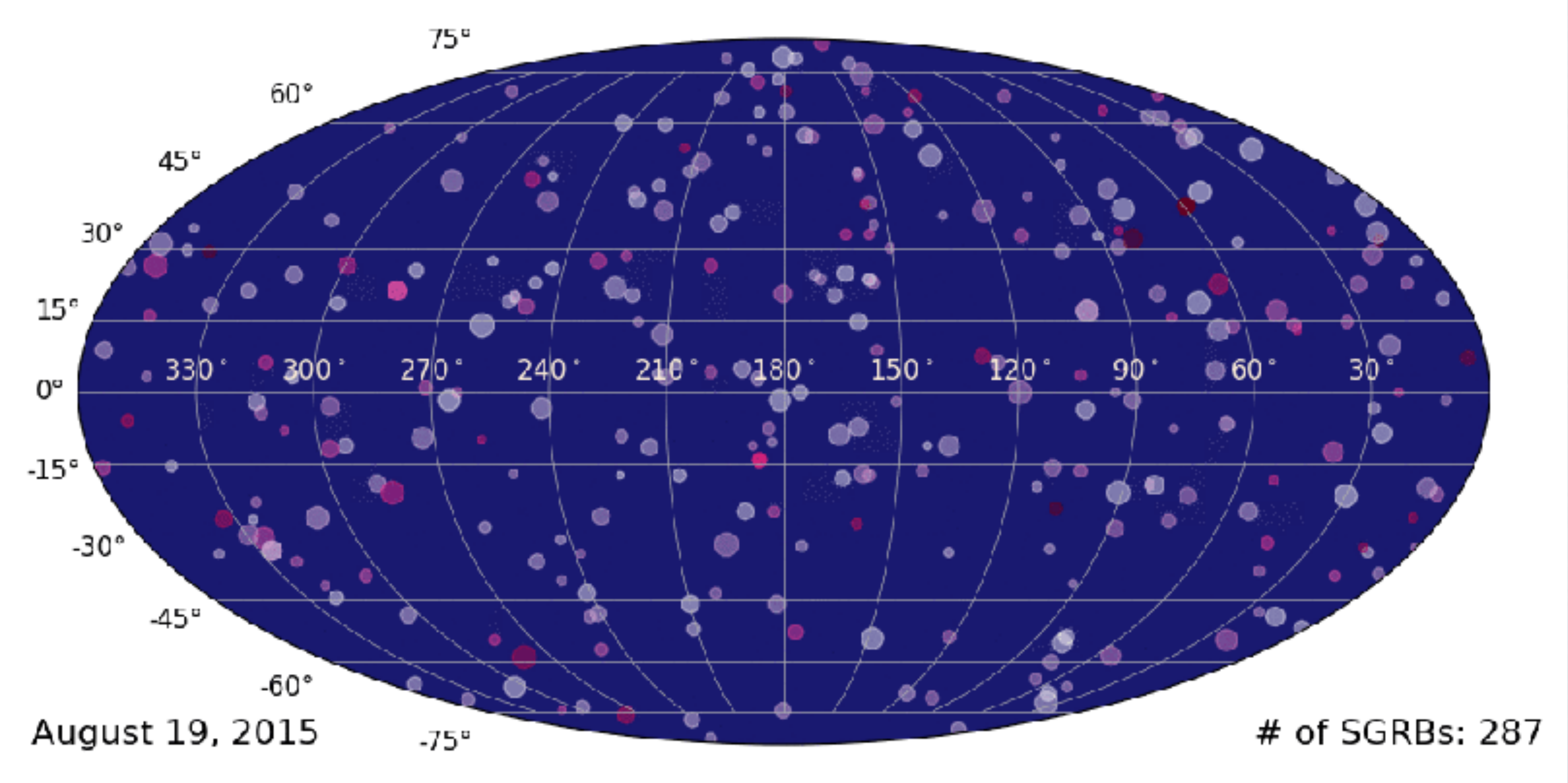
RELATIVISTIC TRANSIENTS

- **Gamma-ray Bursts (GRBs)**
  - most energetic explosions in the Universe.
  - detectable in all wavelengths from radio to gamma rays.
  - can generate multi-messenger signals: gravitational waves, neutrinos, and cosmic rays.

- **Transient nature**
  - prompt emission in gamma rays, lasting <1 sec to >100 sec.
  - afterglow starting within minutes and can last up to years.
  - detectable ~once per day, distributed all over the sky.

- **Era of Multi-Messenger Astrophysics**
  - 2017-08-17: The merger of two neutron stars was detected in both gravitational waves and gamma rays, and subsequent kilonova and afterglow detection across the entire electromagnetic spectrum.
  - Open questions remain such as merger and jet geometry, intrinsic properties etc., progress requires a population of joint detections.





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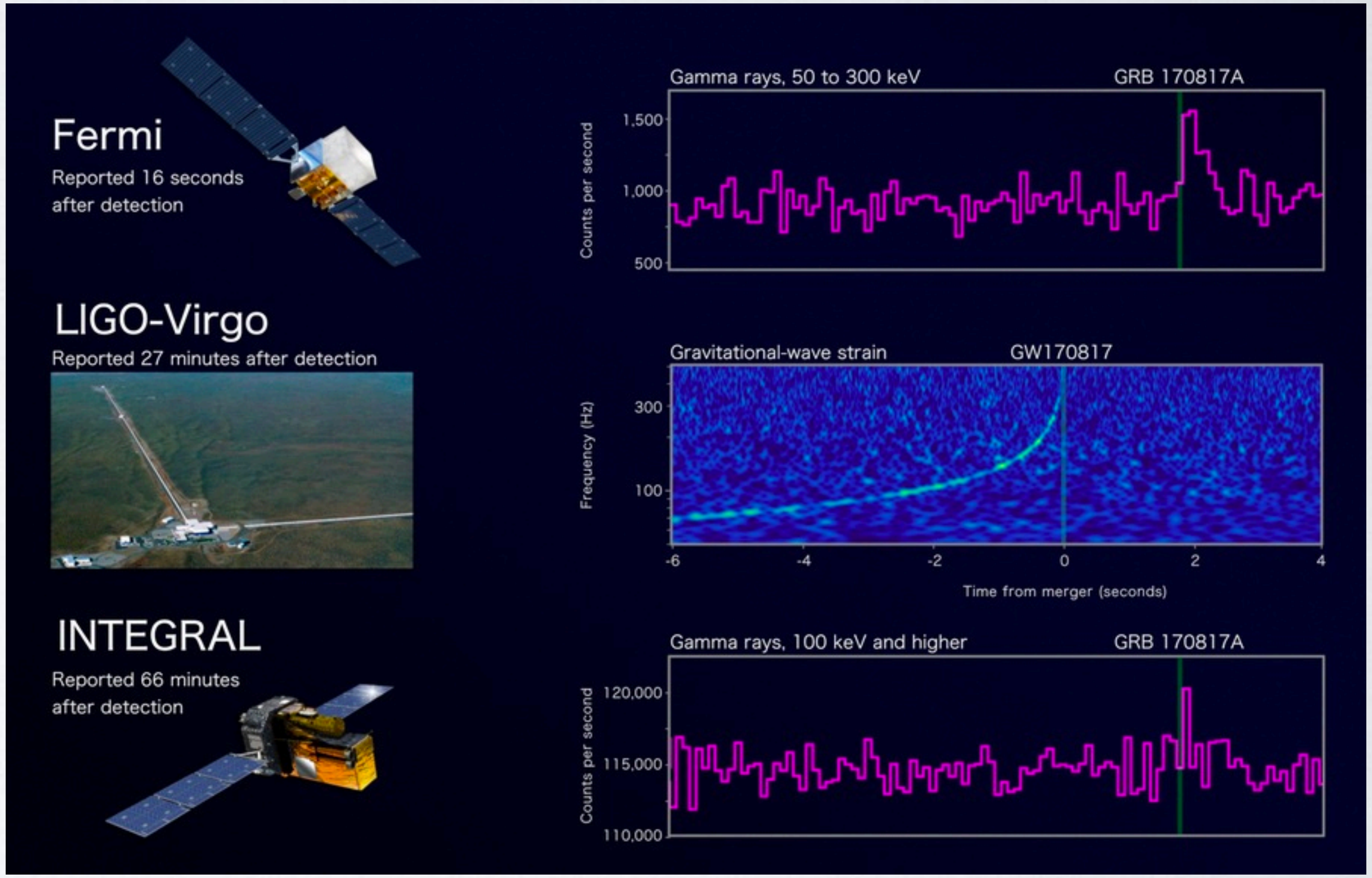
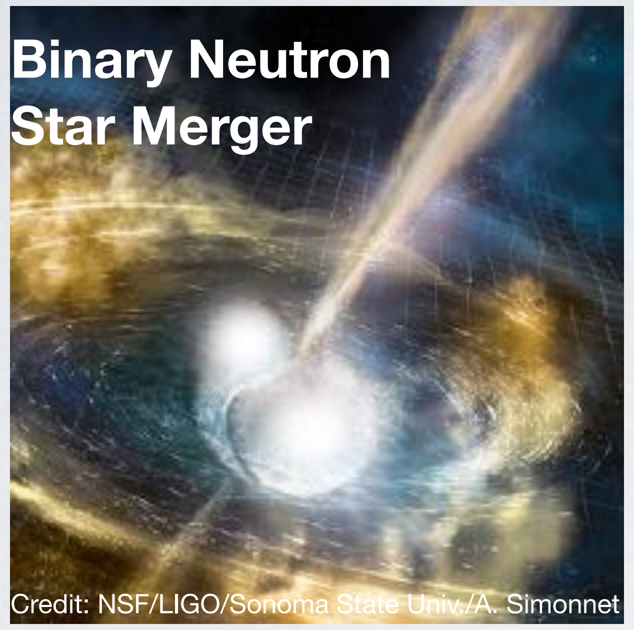


MISSION GOAL AND OBJECTIVES

- Mission Goal: Explore the behavior of matter and energy in its most extreme environments
    - Objective 1: Characterize the progenitors of gamma-ray bursts and their multi-messenger and multi-wavelength signals



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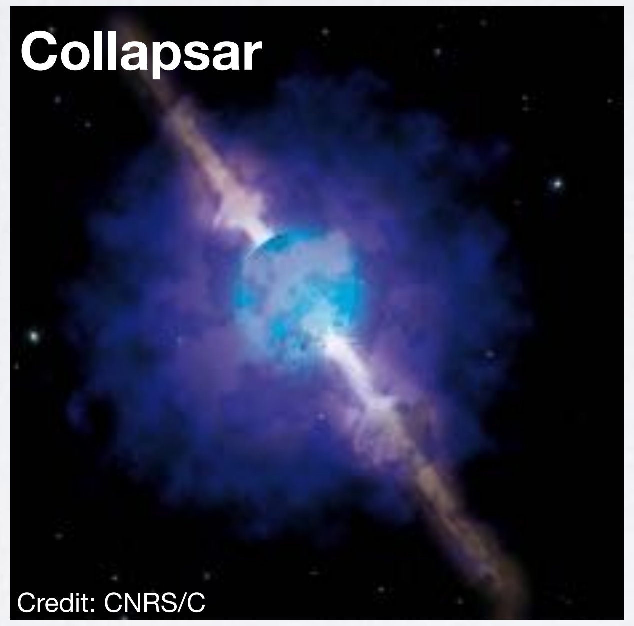

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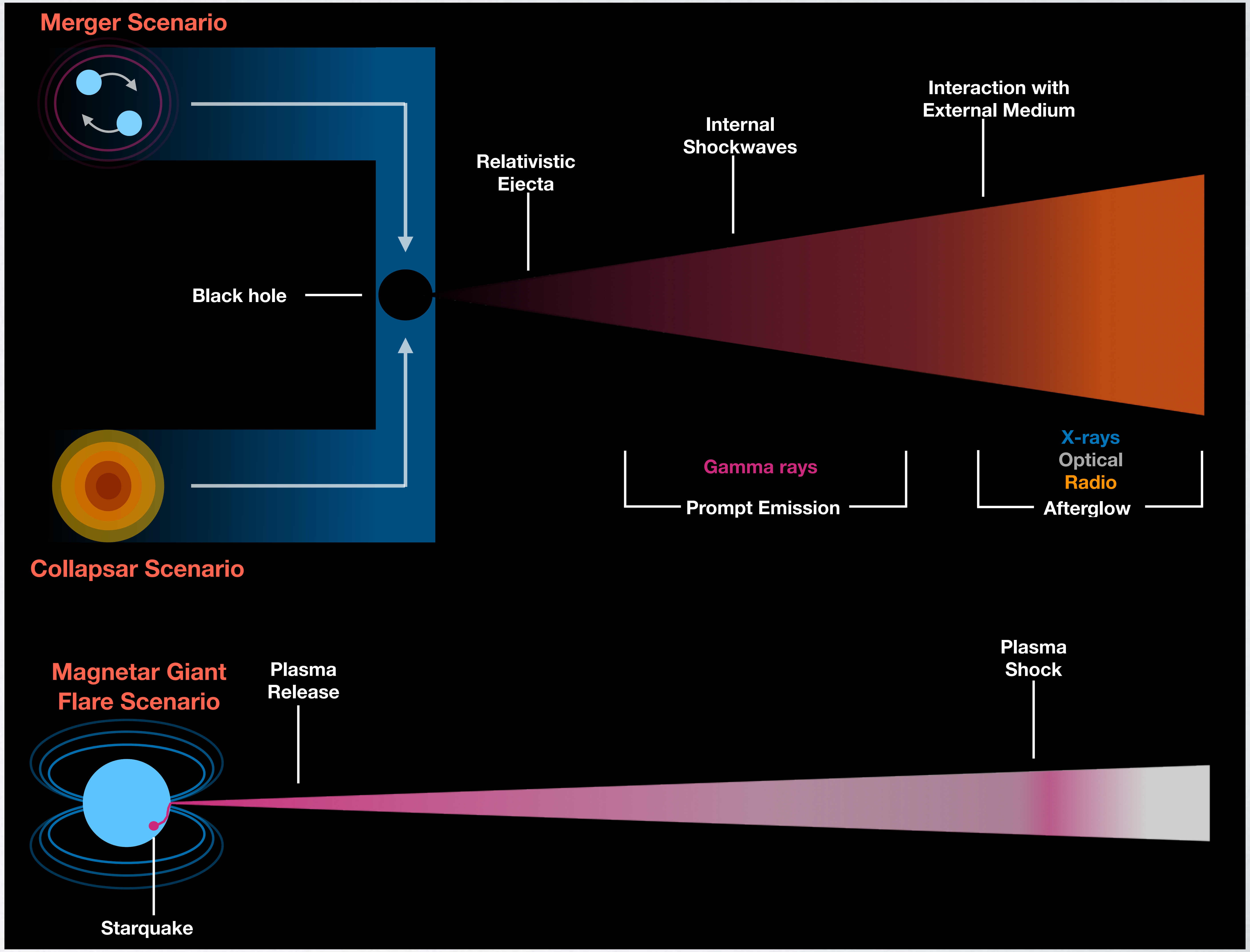

Astro2020 Decadal Survey: Time Domain Astrophysics Program (Highest Priority Sustaining Activity for Space)

"Exploring the cosmos in the multi-messenger and time domains is a key scientific priority for the coming decade, with new capabilities for discovery on the horizon with the Rubin Observatory, Roman, LIGO/Virgo and the Kamioka Gravitational Wave Detector (KAGRA), and IceCube."

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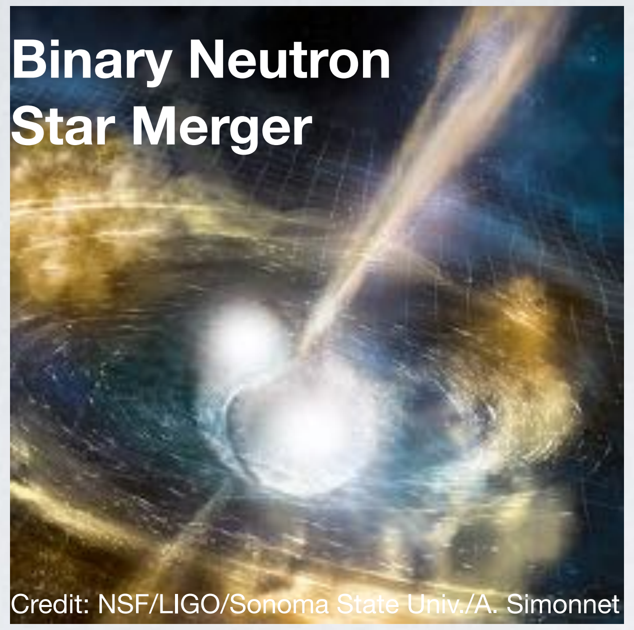

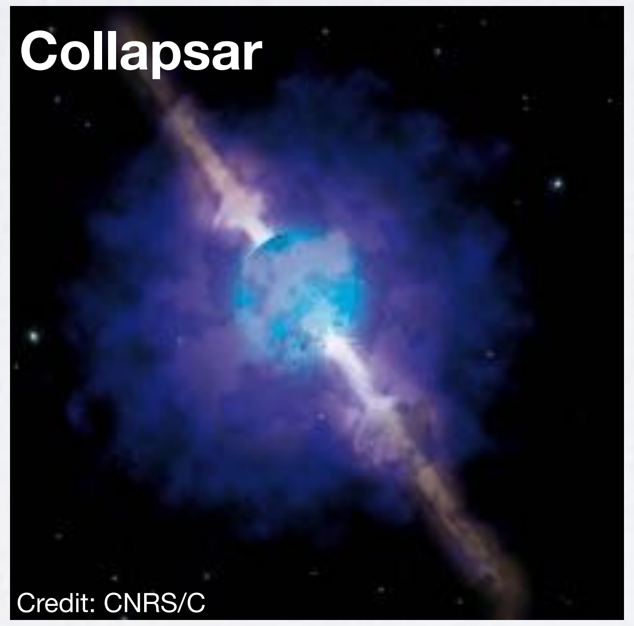

- Binary Neutron Star Merger
  - Joint gravitational-wave and electromagnetic (EM) detections in 2017, confirmed progenitor of short GRBs.
- Neutron Star Black Hole Merger
  - Potential progenitor of short GRB and EM emissions, yet to be confirmed.
- Collapsar
  - a type of fast-rotating core-collapse supernovae.
  - first GRB progenitor to be directly confirmed.
  - potential subclasses:
    - nearby low-luminosity GRBs
    - ultra-long GRBs
- Magnetar Giant Flare
  - highly magnetized neutron star producing short (hundreds of milliseconds) outbursts.
  - relativistic outflow released by surface rupturing / starquakes.

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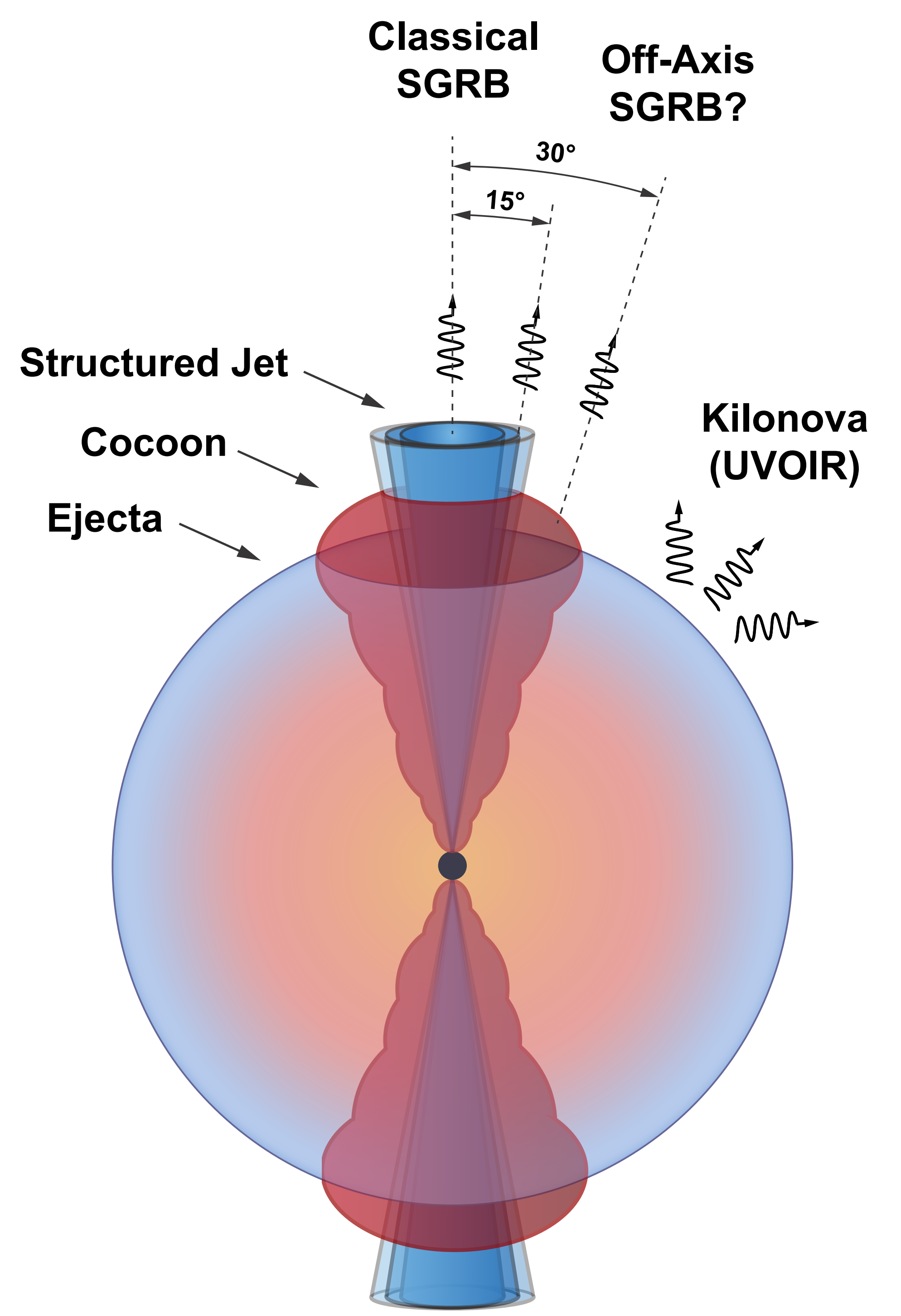
  - Objective 2: Identify conditions necessary to launch a transient astrophysical jet



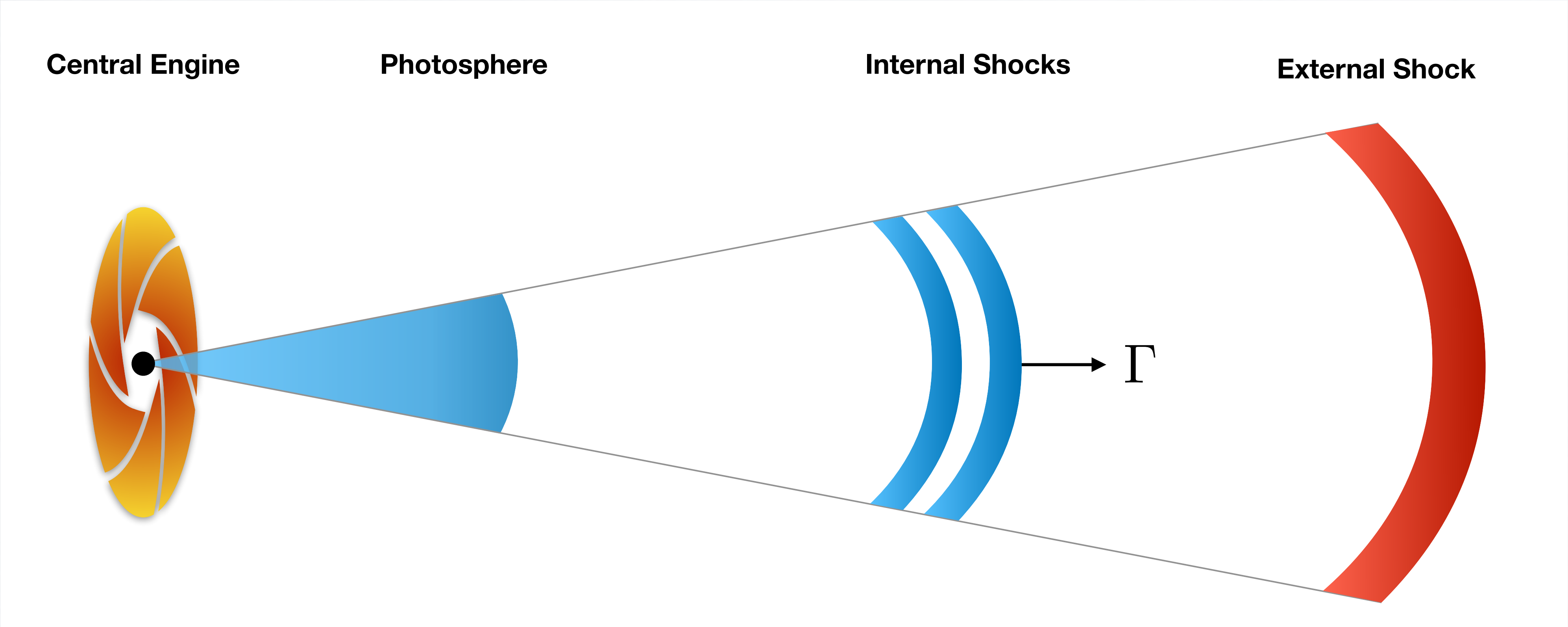
Neutron Star Merger
Polar Ejecta, Structured Jet, & Cocoon

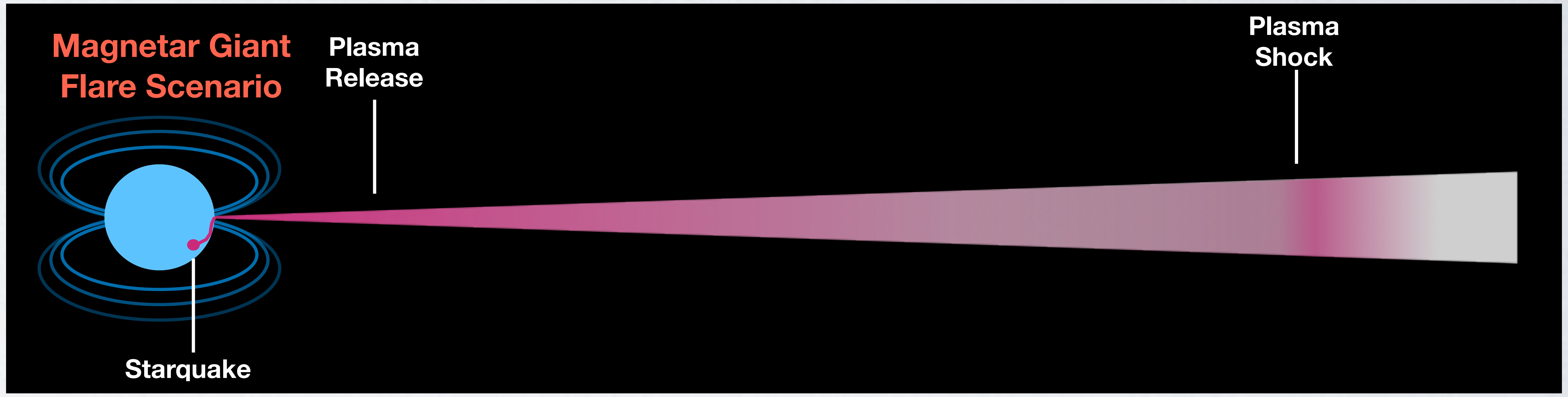
- A spectrum of jets, from completely failed (choked) to ultra-relativistic.
- Jet launch mechanisms:
  - magnetic (Blandford-Znajek mechanism)
  - neutrino - antineutrino annihilation
- Central engine powering the jet with the observed temporal and spectral properties:
  - black hole
  - magnetar?

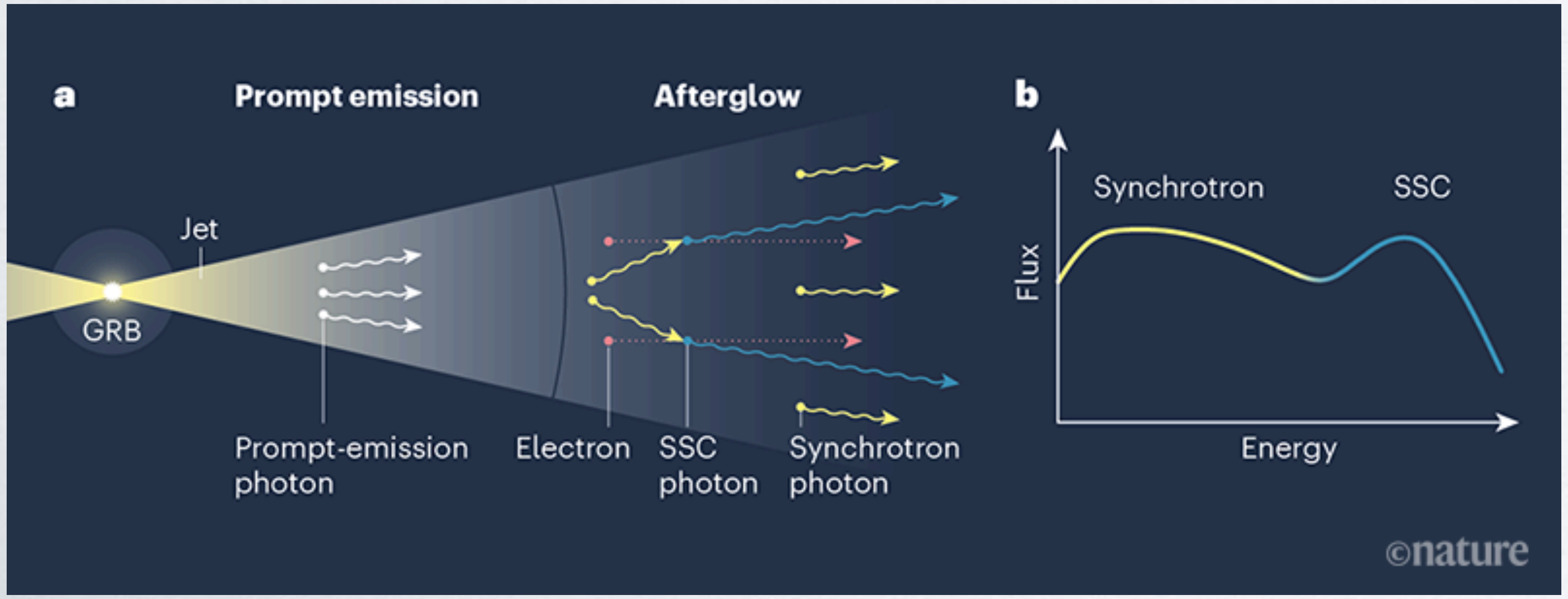
Astro2020 Decadal Survey: “Understanding the central engines (newly formed compact objects like magnetars and BHs) that power many explosive transients continues to be a fundamental astrophysical challenge.”

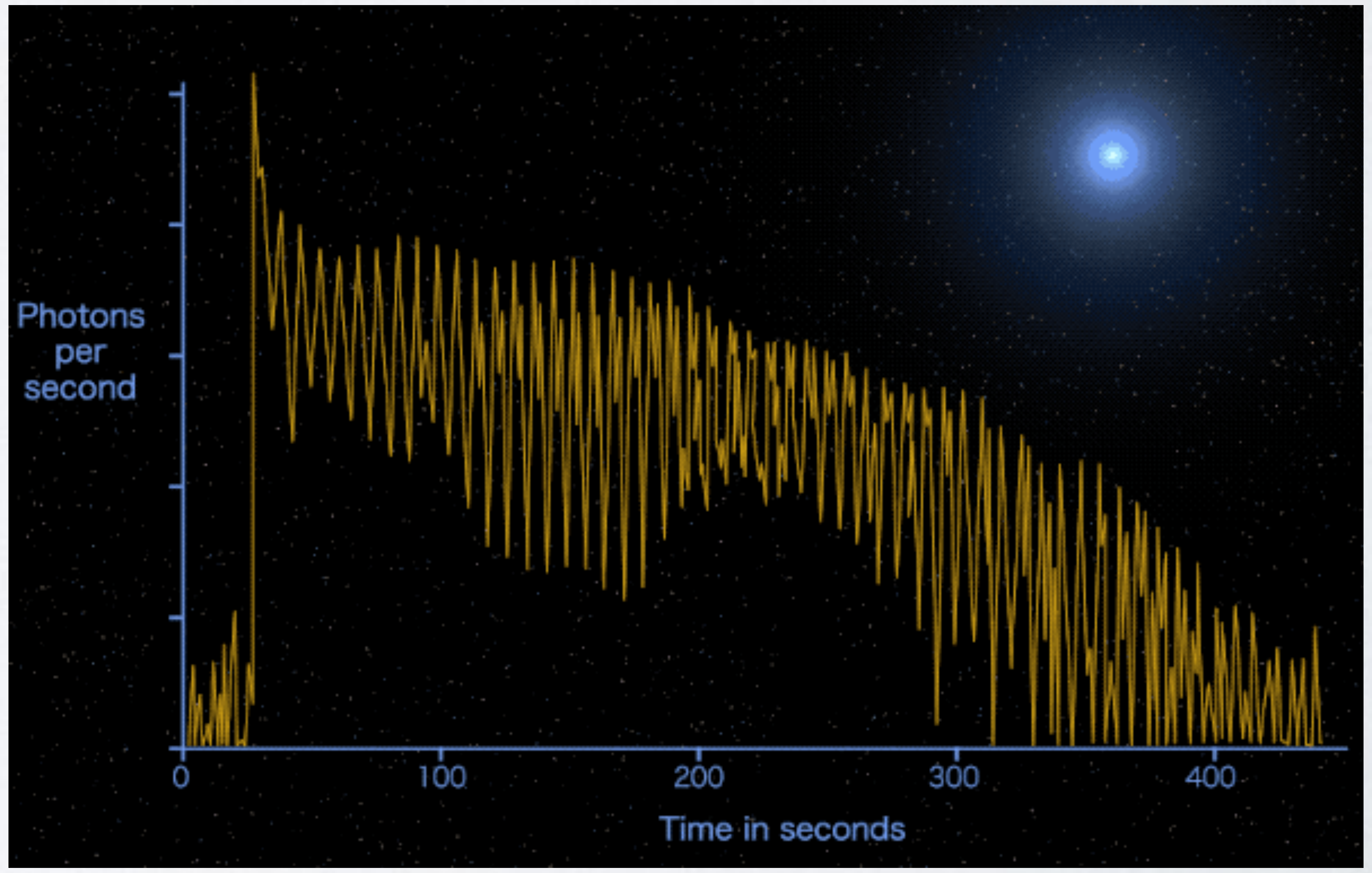
MISSION GOAL AND OBJECTIVES

- Mission Goal: Explore the behavior of matter and energy in its most extreme environments
  - Objective 1: Characterize the progenitors of gamma-ray bursts and their multi-messenger and multi-wavelength signals
  - Objective 2: Identify conditions necessary to launch a transient astrophysical jet
  - Objective 3: Determine the origins of the observed high-energy emission within the relativistic outflow









MISSION GOAL AND OBJECTIVES

- Mission Goal: Explore the behavior of matter and energy in its most extreme environments
  - What are the physical characteristics of stellar explosions that lead to a relativistic transient?
  - What conditions lead to the range of jet scenarios, from a failed jet to an ultra-relativistic jet?
  - What are the different emission mechanisms that convert the relativistic outflow into radiation?
  - What is the distribution of outflow widths and what determines the outflow width?
  - What is the velocity distribution of ejecta across the transverse axis of the outflow?

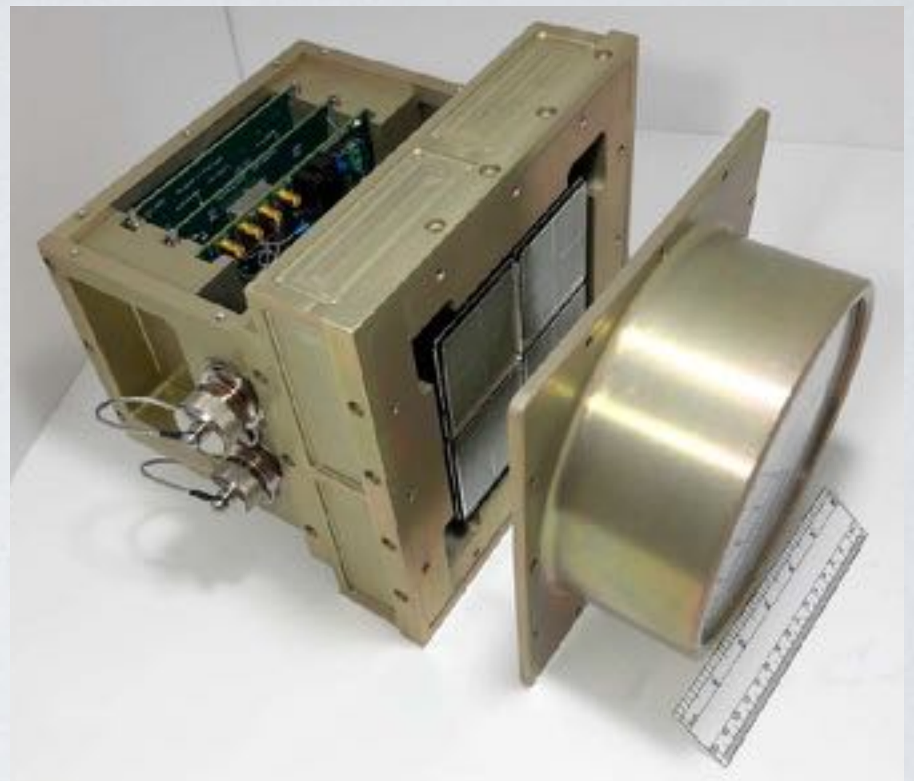
- Key open questions from the 2019 GW-EM task force report:
  - What conditions are necessary to produce relativistic jets, and what is their composition/structure?
  - Do black hole - neutron star and binary black hole mergers produce electromagnetic signals?
  - Can binary neutron star mergers reproduce the relative and total abundances of heavy (r-process) elements?
  - What is the current expansion rate of the Universe (Hubble constant)?
  - What is the equation of state of dense nuclear matter?

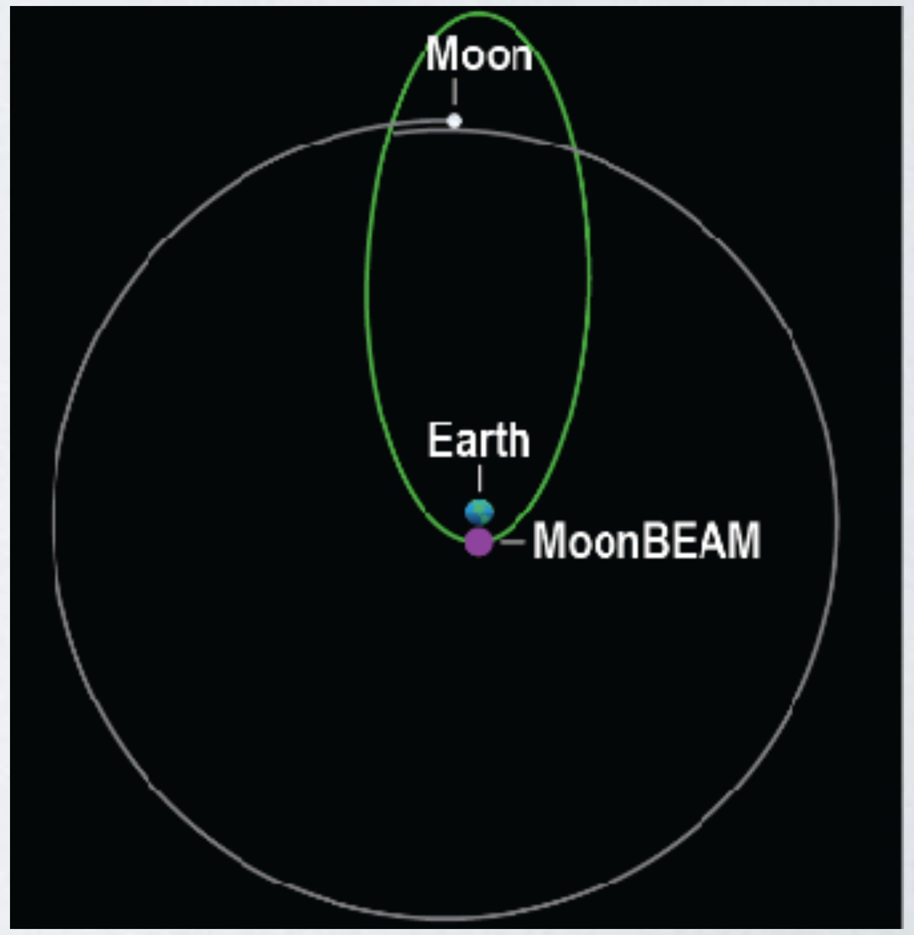
Addressed by MoonBEAM

Enabled by MoonBEAM

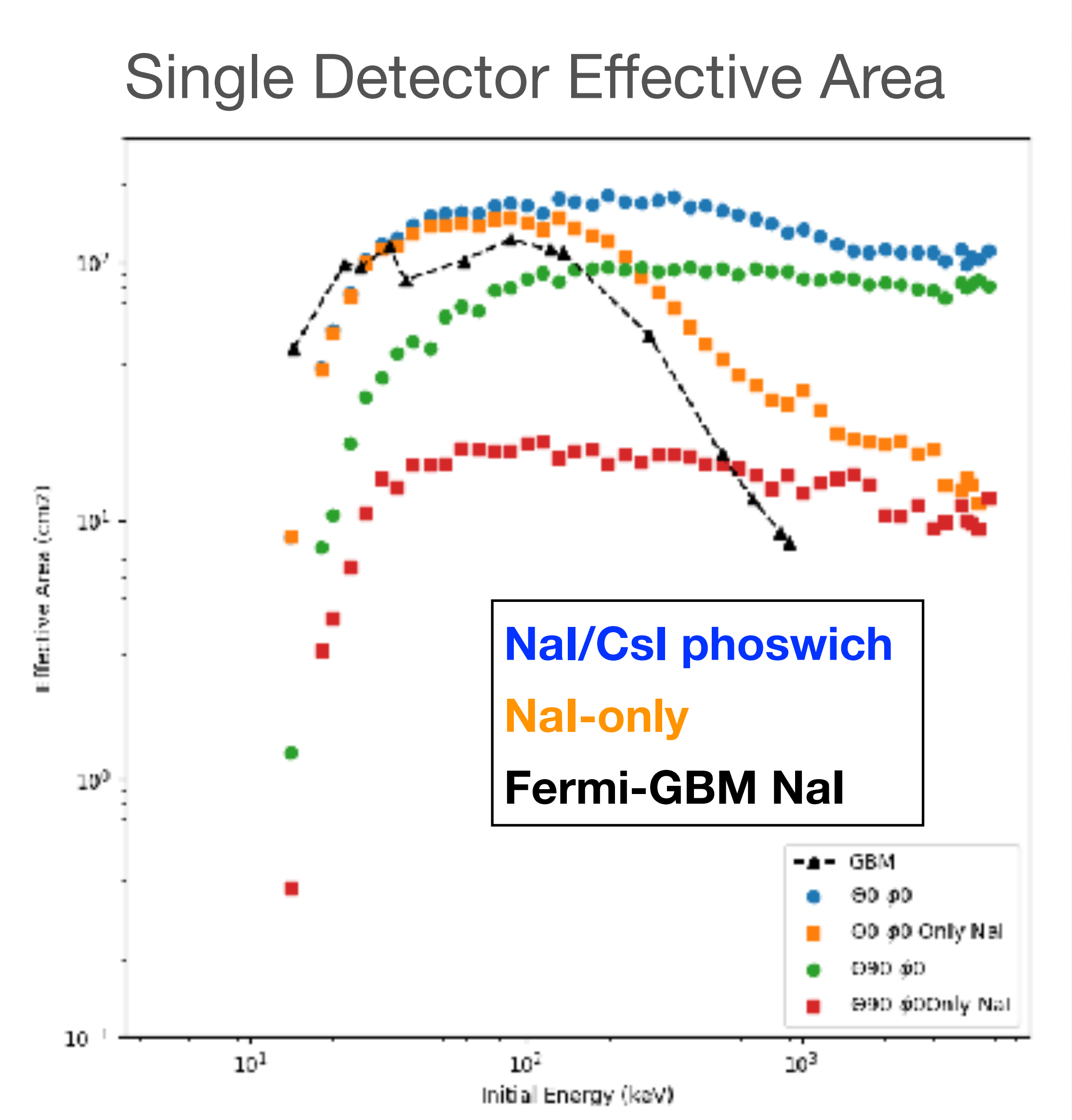
MISSION DESIGN

- Instrument
  - 6 scintillating detectors positioned for instantaneous all-sky coverage, no pointing needed.
  - each detector module consists of a NaI(Tl)/CsI(Na) phoswich and flat panel PMTs, sensitive to 10—5000 keV.
  - phoswich design enables simultaneous dual-mode observations:
    - low background, direction dependency for localization
    - wide energy range and wide field-of-view for spectroscopy
- Lockheed Martin SmallSat spacecraft bus
  - reusing >90% of high-maturity Lunar Trailblazer design.
  - compatible with ESPA Grande mass and volume constraint.
  - high-heritage deep space propulsion approach to lunar resonant orbit from *any* Geosynchronous Transfer Orbit (GTO) rideshare launch.
- Orbital distance up to 460,000km from Earth (1.5 light-seconds).
- Orbital period of 13.7 days.
- Mission lifetime of 3 years.
- Communication
  - continuous burst alert coverage with dedicated ground stations.
  - daily data downlink with the Near Space Network.

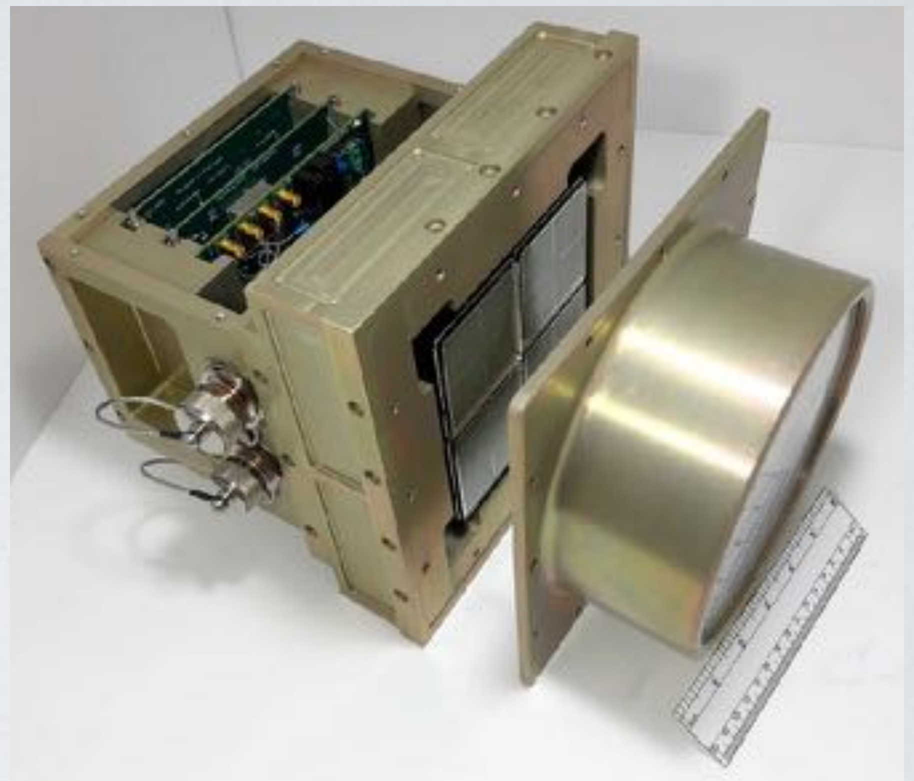


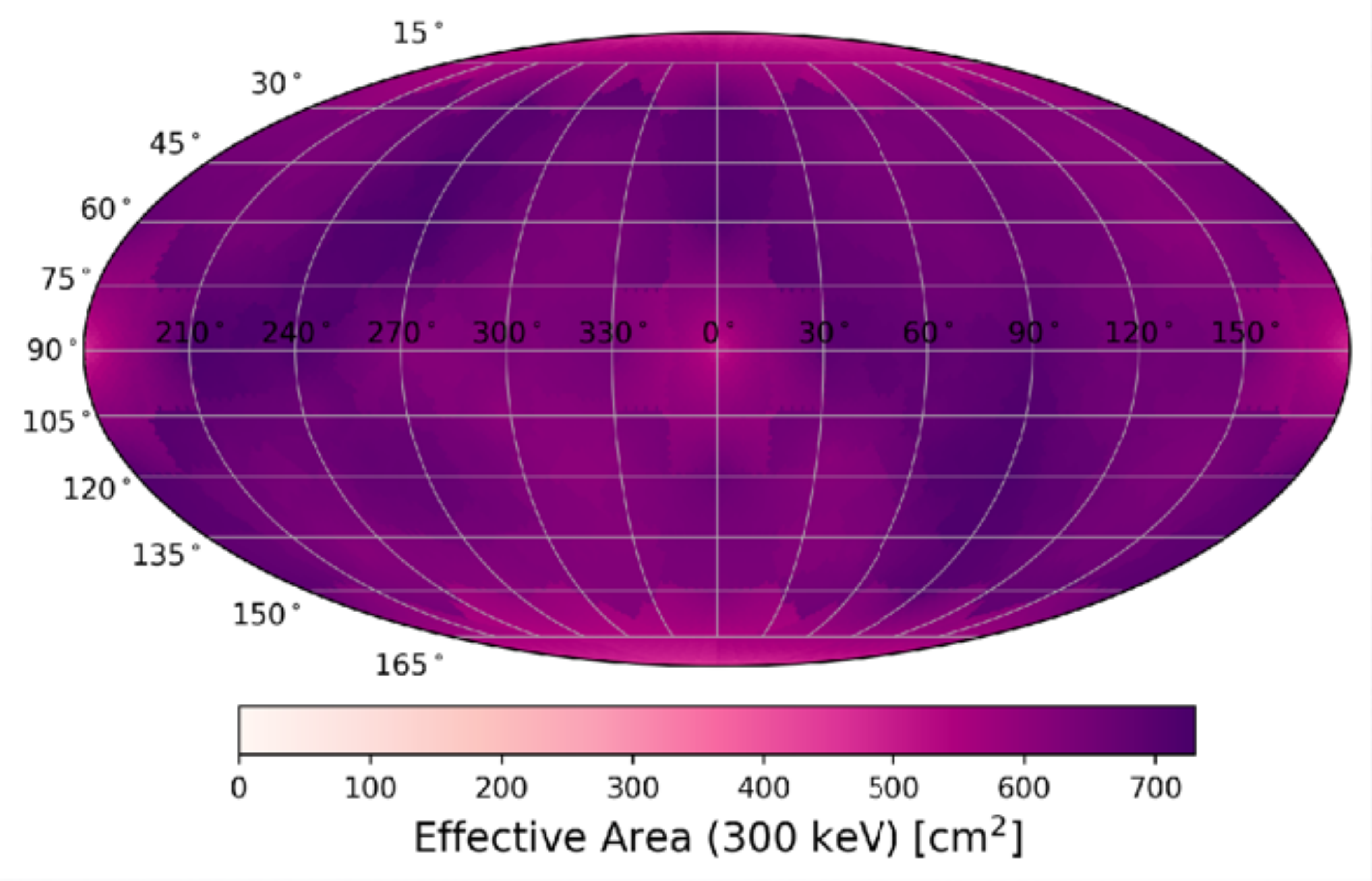


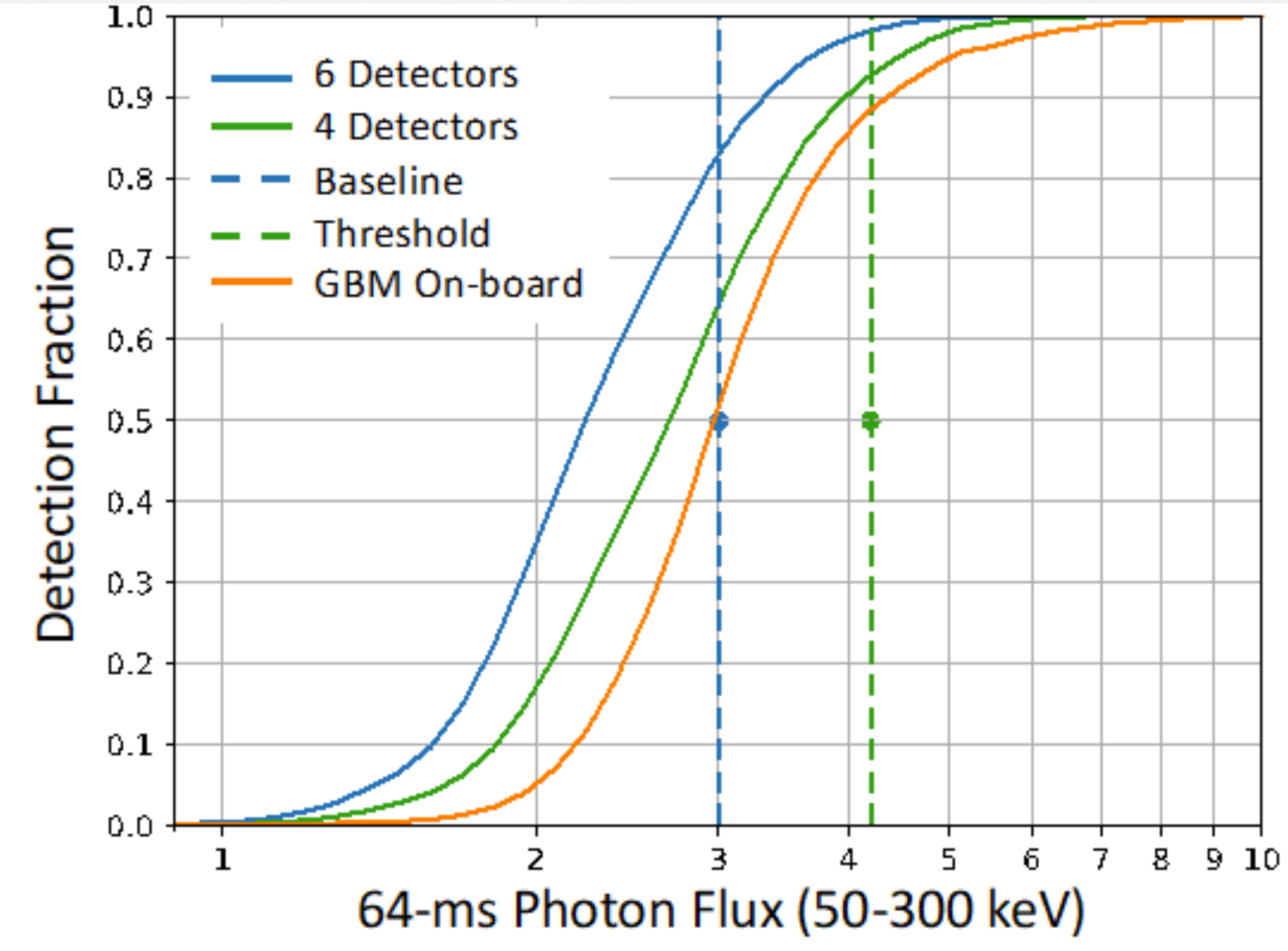
INSTRUMENT PERFORMANCE

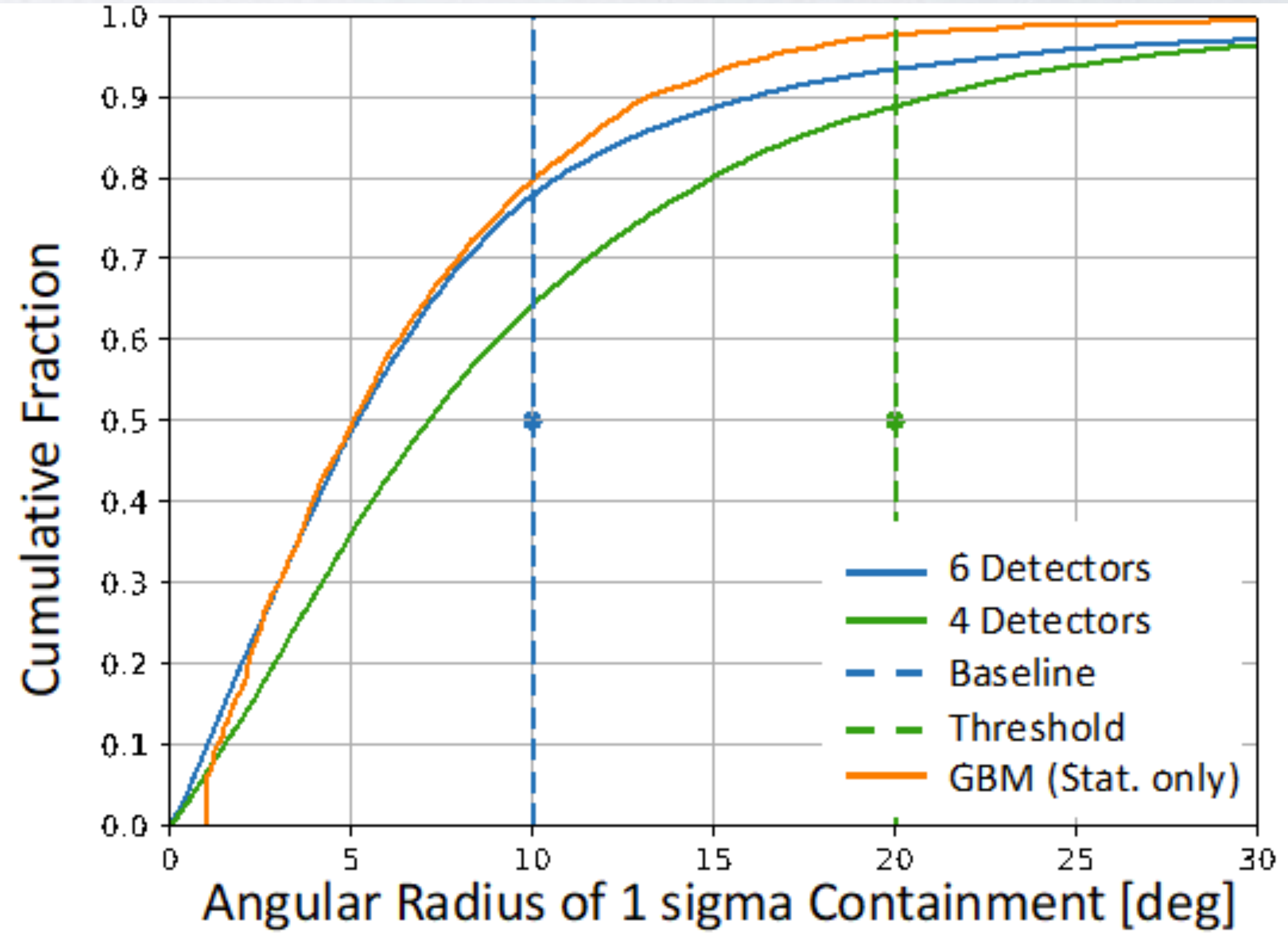


- Instrument
  - 6 scintillating detectors positioned for **instantaneous all-sky coverage, no pointing needed**.
  - each detector module consists of a NaI(Tl)/CsI(Na) phoswich and flat panel PMTs, sensitive to 10—5000 keV.
    - ▸prompt GRB peak energy range
  - phoswich design enables simultaneous dual-mode observations:
    - low background, direction dependency for localization
    - wide energy range and wide field-of-view for spectroscopy

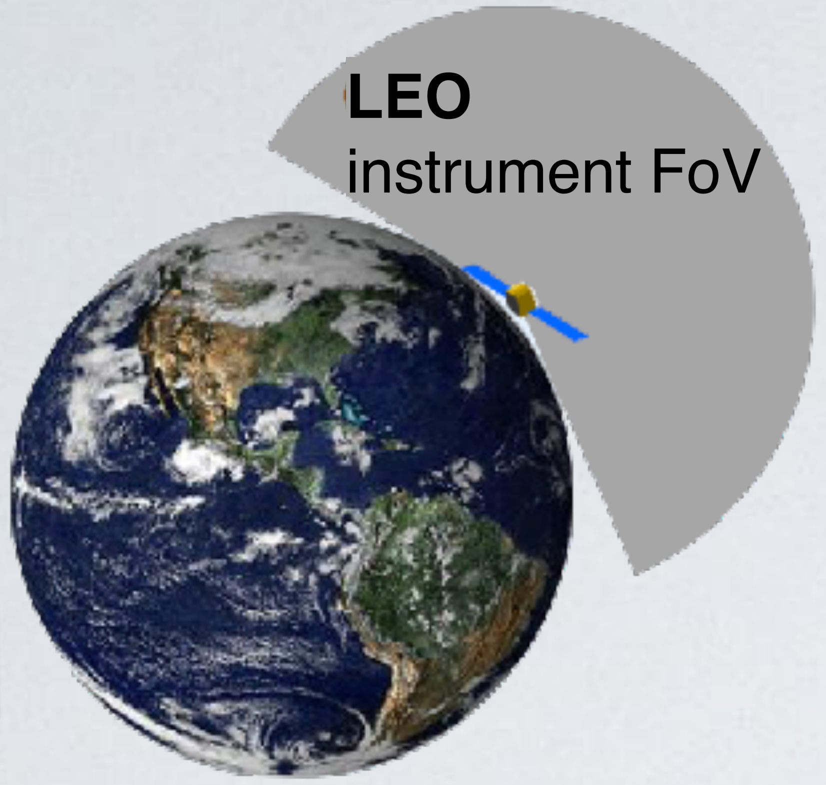


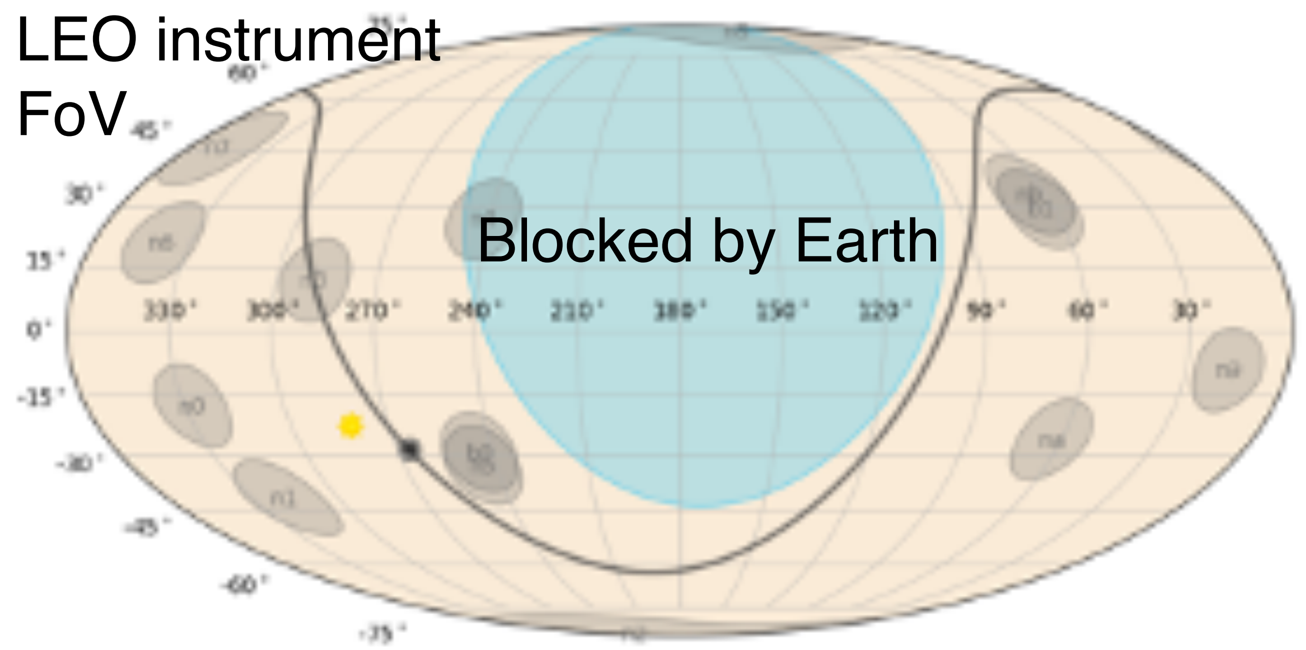


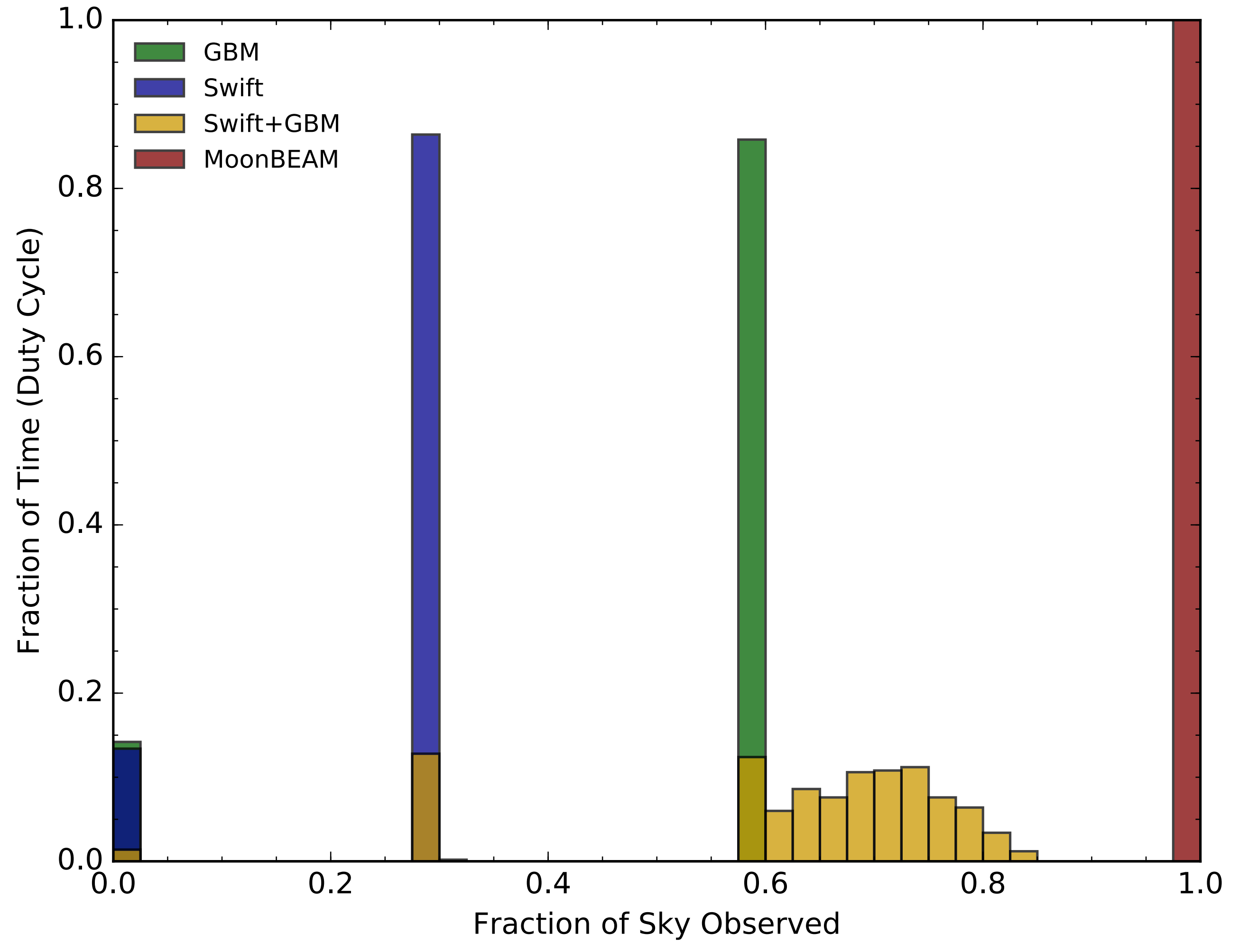




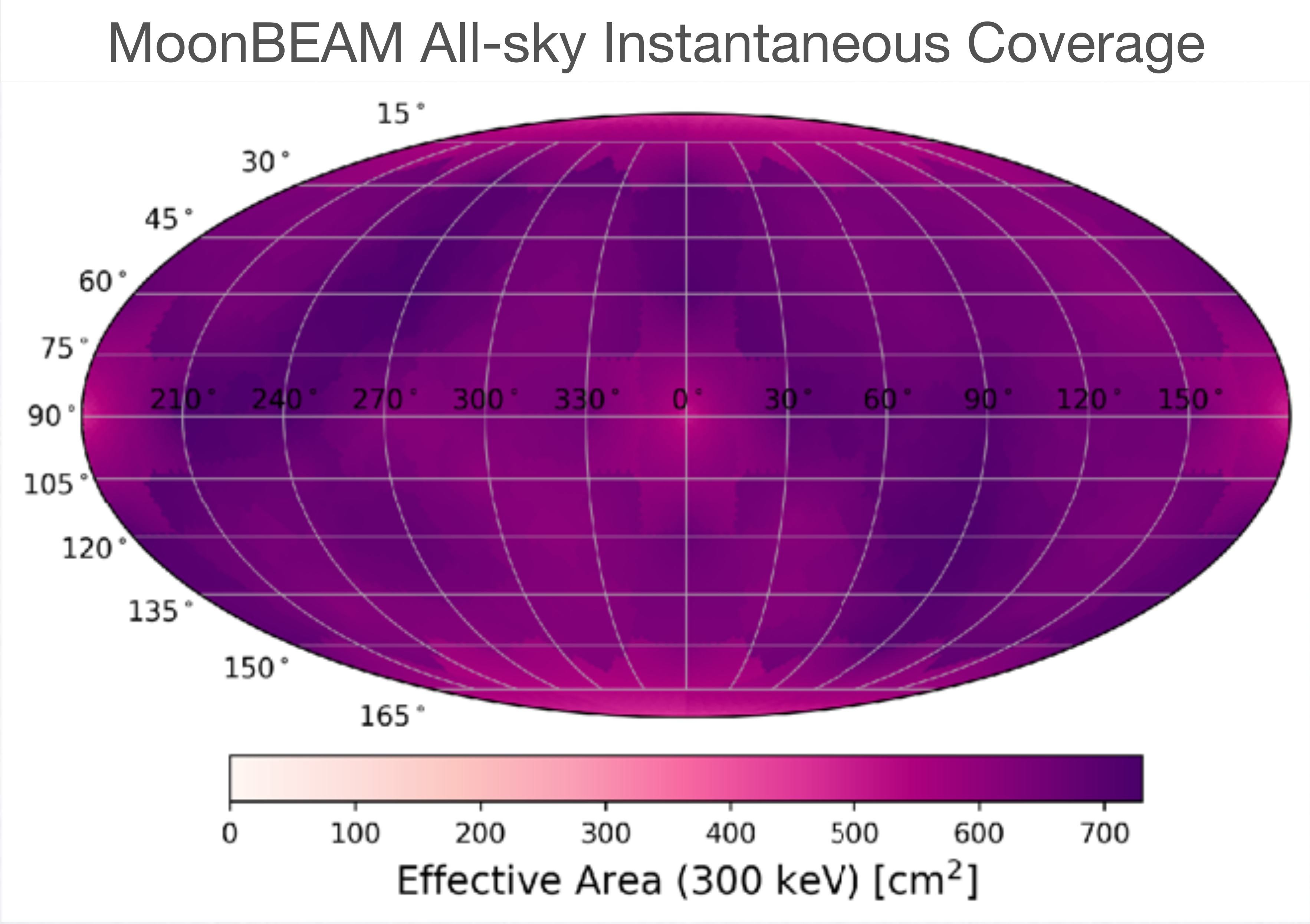
MISSION CAPABILITY

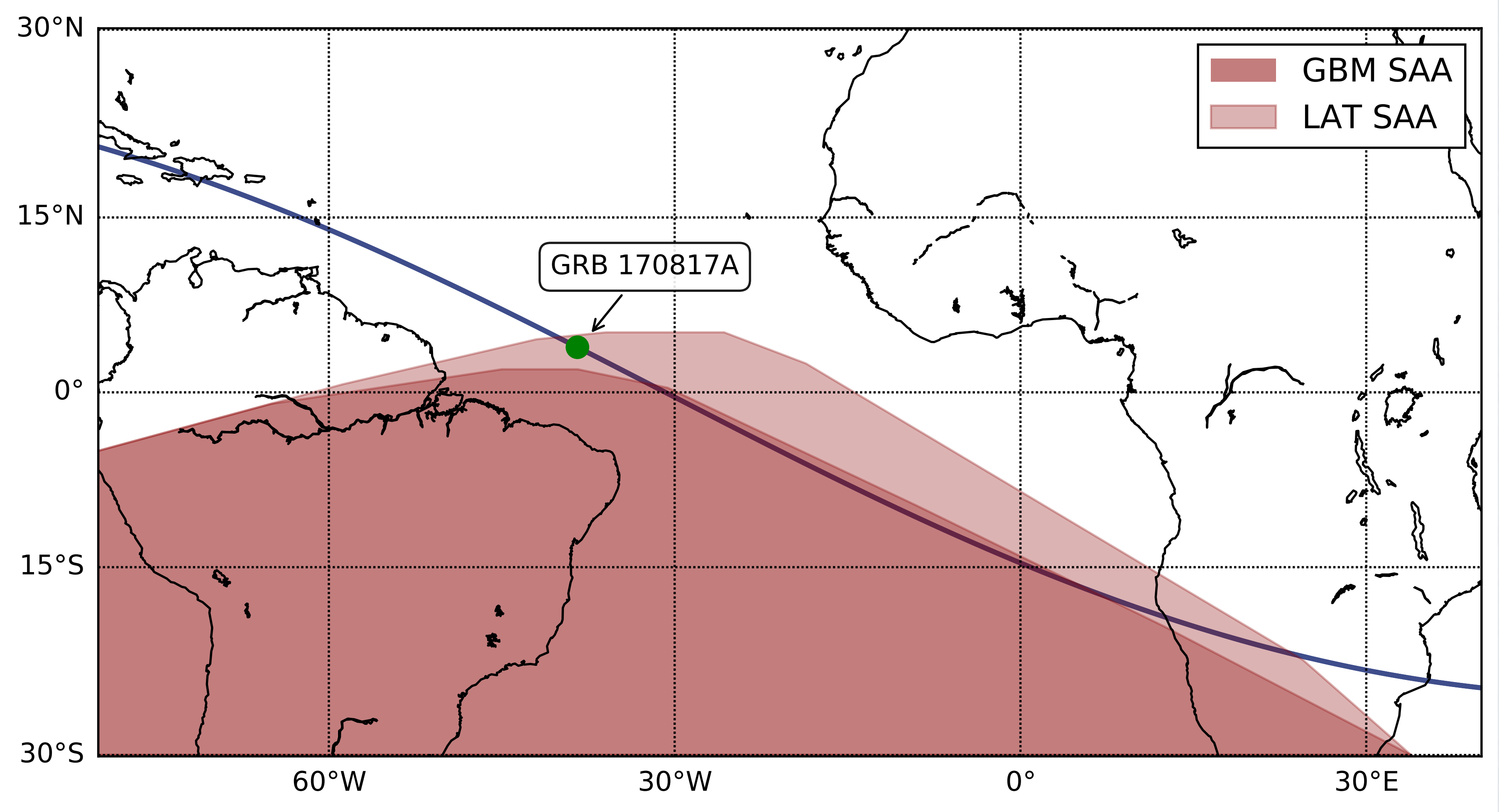






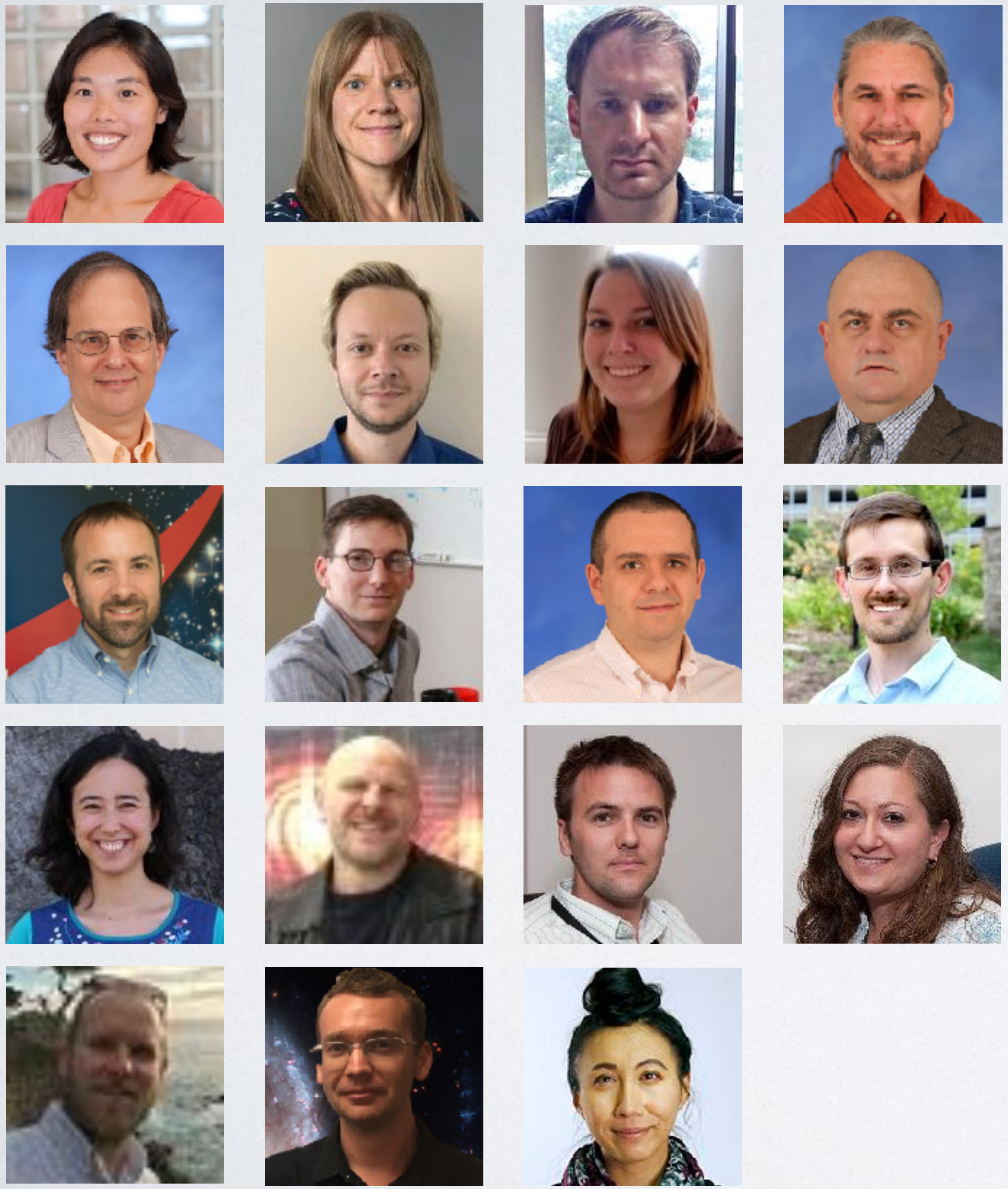
- Orbital distance 22,000km to 460,000km from Earth (up to 1.5 light-seconds).
  - **Instantaneous all-sky field of view**: Earth occults ~2% of the sky at closest approach, <<1% on average.
  - **high duty cycle >96%, 13+ days uninterrupted livetime**: no passage through the South Atlantic Anomaly (SAA).
  - **more stable background** compared to Low Earth Orbit: no atmospheric scattering and SAA-related radiation.
  - **additional localization improvement** using timing triangulation technique with other gamma-ray missions.





Fermi-GBM turned off for SAA 2 minutes after GRB 170817A / GW170817.

MANAGEMENT AND TEAM



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Deputy PI: Colleen Wilson-Hodge (MSFC)
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Instrument Scientist: Peter Jenke (UAH)

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Eric Burns (LSU)
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Judith Racusin (GSFC)
Oliver Roberts (USRA)
Jacob Smith (GSFC)
Sylvia Zhu (DESY Zeuthen)

SUMMARY

MoonBEAM provides essential gamma-ray observations of relativistic astrophysical transients with the following capabilities:

- instantaneous all-sky field of view from lunar resonant orbit.
- 13+ days of uninterrupted livetime.
- stable background for ultra long duration GRBs.
- sensitive to prompt GRB emission energy range, with broad coverage for spectroscopy.
- independent localization and longer baseline for additional localization improvement with other gamma-ray missions.
- rapid alerts to the astronomical community for contemporaneous and follow-up observations.

The era of transient and multi-messenger astronomy: to construct a comprehensive picture of stellar explosions, simultaneous broadband observations are needed.

Potential future collaborations with MoonBEAM:

- LIGO Laboratory
- IceCube Neutrino Observatory
- InterPlanetary Network for Gamma-ray Bursts
- Cherenkov Telescope Array Consortium
- Southern Wide-field Gamma-ray Observatory

Astro2020 Decadal Survey: Astronomical Transient Events

"Higher sensitivity all-sky monitoring of the high-energy sky, complemented by capabilities in the optical such as from Kepler and TESS, is a critical part of our vision for the next decade in transient and multi-messenger astronomy."